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Continued research, development and construction of a state of the art impact testing lab for eyewear: Instrument calibration portion

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Abstract

The purpose of this thesis is to calibrate a pre-existing high-velocity ballistic firing device capable of projecting various sized sports balls with variable velocities at eyewear mounted on a head form. Four sports balls have been tested and calibrated with the results displayed in a table format for easily accessible findings. A laser timer linked to the Datasource computer program was used to make precise measurements of time and speed.

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nike, ballistics, lenses, impact, sports

Subject Categories

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CONTINUED RESEARCH, DEVELOPMENT AND CONSTRUCTION OF A STATE OF THE ART IMPACT TESTING LAB FOR EYEWEAR: INSTRUMENT CALIBRATION PORTION

BY

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Biographies

Ian Ford has attended Pacific University College of Optometry since 2003. He received his undergraduate education at Pacific University, Montana State University – Bozeman, and the University of Mary in Bismarck, North Dakota, earning his undergraduate degree with a B.S. in Biology with a Chemistry minor. Upon receiving his doctorate of optometry degree, he plans on returning to Montana to practice optometry.

Aqil Habib has attended Pacific University College of Optometry since 2003. He received his undergraduate education at the University of Washington in Seattle and Pacific University earning his undergraduate degree with a B.S. in Vision Science. Upon receiving his doctorate of optometry degree, he plans on returning to Seattle, Washington to practice optometry.

ABSTRACT

The purpose of this thesis is to calibrate a pre-existing high-velocity ballistic firing device capable of projecting various sized sports balls with variable velocities at eyewear mounted on a head form. Four sports balls have been tested and calibrated with the results displayed in a table format for easily accessible findings. A laser timer linked to the Datasource computer program was used to make precise measurements of time and speed.

Key Words: Nike, Ballistics, Lenses, Impact, Sports

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Introduction

In the year 2000, Chad Roberts and Stephen Reigstad began a thesis project aimed at giving Pacific University College of Optometry a "State of the Art" impact testing lab for eyewear. The first part of this project, completed in 2001, dealt with the research, development, and construction of a drop ball apparatus consisting of variable sized and weighted objects that could be dropped from chosen heights onto selected eyewear or lens blanks. The second part of this project, completed by Dustin Bodman, Ryan Hogan, and David Biggar in 2004, dealt with the research, development, and construction of a high-velocity ballistic firing device capable of projecting various sized sports balls with variable velocities at eyewear mounted on a head form. The third part of this project, running from 2005 thru 2006, dealt with the calibration of this machine as well as making improvements to the design. The advisors for all portions of the lab design are Dr. Alan Reichow and Dr. Karl Citek, who are both professors at Pacific University College of Optometry.

Methods

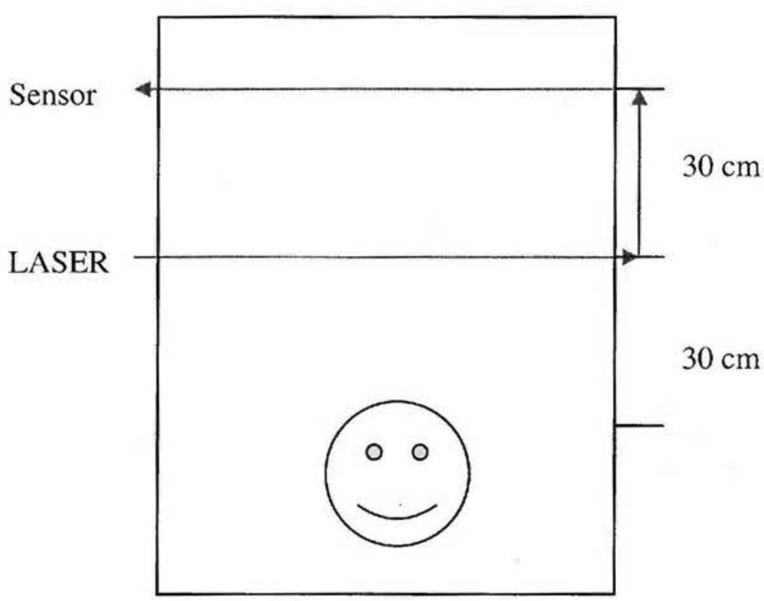
The first improvement for the ballistics machine was to investigate the possibility of high-speed imaging. With high-speed imaging, videos and still images could be examined, showing the entire impact process during testing. This would allow for better interpretation of the results, as well as offering some awfully interesting photographs. The camera would be mounted outside of the machine and cover a 30 cm x 30 cm area, centered on head form. Questions arose regarding a degraded image through the ½" polycarbonate, but it was determined that for the safety of the camera, this would be the best choice.

Calculations for the speed and resolution needed for this camera were based on a maximum testing speed of 80 mph, or 35.8 m/s, and a necessary field of view of 30 x 30 cm. This meant a ball would travel through our field of view in 8.4 ms. In order to capture 20 frames during this span, a camera with a speed of at least 2384 frames per second (fps) would be necessary. As for the resolution needed for this camera, the area needed to capture in the field of view was 900 cm^2. In order to have high enough quality of resolution over this area, a camera with at least 3 megapixel (2048 horizontal x 1536 vertical pixels) capability would be necessary. This would allow for 68 pixels per 1 cm horizontally and 51 pixels per 1 cm vertically. Two different companies, Photron and Itronix, were contacted regarding pricing for cameras with such capabilities, and it was determined that the cost ($10,000 - $50,000) definitely outweighed the benefit at this current phase of the project.

The next goal of the project was to calibrate the instrument using a laser timer linked to the Datasource computer program for numerous different sports balls. Included in this phase of the project were the tennis ball, baseball, softball, and volleyball. Being that the Juggs machine had been calibrated for a specific ball with a specific spacing, its calibration was no longer accurate, and therefore could only be used as an estimate.

The initial set-up of this laser gate consisted of a laser mounted to a tripod aimed through a hole in the polycarbonate casing at a mirror on the other side. This mirror reflected the laser beam to another mirror, which in turn reflected the beam to a sensor. When the ball passed through the first beam, the switch would be shut off, then turned on again when the ball cleared the beam. The same thing would occur when the ball passed through the second laser (see Figure 1). These four times were captured by the Datasource program, then transferred to a Microsoft Excel spreadsheet to determine the true velocities of the projected balls.

Figure 1.



In order to make the machine more aesthetically pleasing, an attempt was made to mount the laser, the mirrors, and the sensor to the frame of the machine. Not only would this would get rid of the cinder blocks and tripods, but it should have also made the alignment process much easier. Using pipe fittings, test-tube holders, and corrugated metal rods, the instruments needed for the laser gate were mounted to the machine's base. A new laser was purchased that ran on AA batteries instead of the previous button battery variety in order to make for easier replacement. This improvement worked until the Juggs machine was turned over its 60 mph indicator. Anything at this speed or higher caused too much vibration of the base, which caused the laser to shift loose, which made it impossible to gather any recordings because the sensor no longer had contact with the laser. Therefore, in order to gather the calculations for this project, the old laser gate setup was utilized.

The methods used to calibrate the Juggs machine for different sports balls were fairly straight-forward. A metal spacer was inserted between the two wheels of the Juggs machine to provide proper spacing for the ball being tested (see Table 1). The speed indicator on the Juggs machine was then turned to an increment of 10, and then 20 trials were run at that speed. Four times were recorded for each ball (when the first switch went off, when it turned back on, when the second switch went off, when it turned back on) and were entered into a spreadsheet. The velocity of the ball was then calculated in both miles per hour and meters per second. An average of the 20 runs as well as the standard deviation was also calculated.

Table 1

Ball	Size of Spacer (cm)
Tennis ball	
Baseball	
Softball	
Volley Ball	
Golf Ball	

Results

Table 2 – Tennis Ball

Juggs "Speed"	Break 1	Recovery 1	Break 2	Recovery 2	Break 1 - Break 2 (seconds)	(hours)	Recovery 1 - Recovery 2 (seconds)	(hours)	m/s – Break	mph – Break	m/s - Recovery	mph - Recovery
20	0.9043	0.9091	0.9268	0.9316	0.0225	6.25E-06	0.0225	6.25E-06	13.77777778	30.82001113	13.77777778	30.82001113
20	0.2859	0.2907	0.3088	0.3135	0.0229	6.36111E-06	0.0228	6.33333E-06	13.5371179	30.28167033	13.59649123	30.41448467
20	0.8857	0.8904	0.9082	0.913	0.0225	6.25E-06	0.0226	6.27778E-06	13.77777778	30.82001113	13.71681416	30.6836394
20	0.8191	0.824	0.8421	0.8469	0.023	6.38889E-06	0.0229	6.36111E-06	13.47826087	30.15001089	13.5371179	30.28167033
20	0.7471	0.7519	0.7698	0.7747	0.0227	6.30556E-06	0.0228	6.33333E-06	13.65638767	30.54846919	13.59649123	30.41448467
20	0.1422	0.147	0.1648	0.1697	0.0226	6.27778E-06	0.0227	6.30556E-06	13.71681416	30.6836394	13.65638767	30.54846919
20	0.7651	0.77	0.7877	0.7927	0.0226	6.27778E-06	0.0227	6.30556E-06	13.71681416	30.6836394	13.65638767	30.54846919
20	0.9476	0.9525	0.9703	0.9751	0.0227	6.30556E-06	0.0226	6.27778E-06	13.65638767	30.54846919	13.71681416	30.6836394
20	0.2074	0.2119	0.2301	0.2346	0.0227	6.30556E-06	0.0227	6.30556E-06	13.65638767	30.54846919	13.65638767	30.54846919
20	0.4852	0.4901	0.5081	0.513	0.0229	6.36111E-06	0.0229	6.36111E-06	13.5371179	30.28167033	13.5371179	30.28167033
20	0.6845	0.6894	0.7074	0.7123	0.0229	6.36111E-06	0.0229	6.36111E-06	13.5371179	30.28167033	13.5371179	30.28167033
20	0.6348	0.6397	0.6577	0.6626	0.0228	6.36111E-06	0.0229	6.36111E-06	13.5371179	30.28167033	13.5371179	30.28167033
20	0.612	0.6168	0.6349	0.6396	0.0229	6.36111E-06	0.0228	6.33333E-06	13.5371179	30.28167033	13.59649123	30.41448467
20	0.8473	0.852	0.8701	0.8749	0.0228	6.33333E-06	0.0229	6.36111E-06	13.59649123	30.41448467	13.5371179	30.28167033
20	0.2081	0.2129	0.2306	0.2355	0.0225	0.00000625	0.0226	6.27778E-06	13.77777778	30.82001113	13.71681416	30.6836394
20	0.0376	0.0425	0.0602	0.0652	0.0226	6.27778E-06	0.0227	6.30556E-06	13.71681416	30.6836394	13.65638767	30.54846919
20	0.8547	0.8597	0.8777	0.8824	0.023	6.38889E-06	0.0227	6.30556E-05	13.47826087	30.15001089	13.65638767	30.54846919
20	0.7544	0.7593	0.7771	0.7821	0.0227	6.30556E-06	0.0228	6.33333E-06	13.65638767	30.54846919	13.59649123	30.41448467
20	0.4606	0.4653	0.4829	0.4877	0.0223	6.19444E-06	0.0224	6.22222E-06	13.90134529	31.09642379	13.83928571	30.95780047
20	0.8084	0.8133	0.831	0.836	0.0226	6.27778E-06	0.0227	6.30556E-06	13.71681416	30.6836394	13.65638767	30.54846919
								Average	13.64830442	30.53038748	13.63888932	30.50928176
								Standard Dev	0.116004051	0.259493672	0.085372313	0.190972424
30	0.6861	0.6894	0.7025	0.7056	0.0164	4.55556E-06	0.0162	0.0000045	18.90243902	42.28355186	19.13580247	42.80557102
30	0.2678	0.2711	0.2841	0.2869	0.0163	4.52778E-06	0.0158	4.38889E-06	19.01840491	42.54296016	19.62025316	43.88925636
30	0.671	0.674	0.6876	0.6896	0.0166	4.61111E-06	0.0156	4.33333E-06	18.6746988	41.77411148	19.87179487	44.45193914
30	0.3185	0.3217	0.3349	0.3376	0.0164	4.55556E-06	0.0159	4.41667E-06	18.90243902	42.28355186	19.49685535	43.6132233
30	0.098	0.101	0.1146	0.1164	0.0166	4.61111E-06	0.0154	4.27778E-06	18.6746988	41.77411148	20.12987013	45.02923705
30	0.7044	0.7075	0.7211	0.7234	0.0167	4.63889E-06	0.0159	4.41667E-06	18.56287425	41.5239671	19.49685535	43.6132233
30	0.9136	0.9166	0.93	0.9326	0.0164	4.55556E-06	0.016	4.44444E-06	18.90243902	42.28355186	19.375	43.34064066
30	0.3651	0.3683	0.3813	0.3842	0.0162	0.0000045	0.0159	4.41667E-06	19.13580247	42.80557102	19.49685535	43.6132233
30	0.7717	0.7745	0.7888	0.7899	0.0171	4.75E-06	0.0154	4.27778E-06	18.12865497	40.55264623	20.12987013	45.02923705
30	0.2304	0.2336	0.2467	0.2495	0.0163	4.52778E-06	0.0159	4.41667E-06	19.01840491	42.54296016	19.49685535	43.6132233
30	0.6527	0.6559	0.6685	0.6715	0.0158	4.38889E-06	0.0156	4.33333E-06	19.62025316	43.88925636	19.87179487	44.45193914
30	0.1997	0.2025	0.216	0.218	0.0163	4.52778E-06	0.0155	4.30556E-06	19.01840491	42.54296016	20	44.73872584
30	0.5006	0.5036	0.5171	0.5194	0.0165	4.58333E-06	0.0158	4.38889E-06	18.78787879	42.02728791	19.62025316	43.88925636
30	0.3263	0.3295	0.3423	0.3452	0.016	4.44444E-06	0.0157	4.36111E-06	19.375	43.34064066	19.74522293	44.16880577
30	0.7379	0.7407	0.7549	0.756	0.017	4.72222E-06	0.0153	4.25E-06	18.23529412	40.79119121	20.26143791	45.32354579
30	0.7594	0.7625	0.7756	0.7781	0.0162	0.0000045	0.0156	4.33333E-06	19.13580247	42.80557102	19.87179487	44.45193914
30	0.2663	0.2695	0.2822	0.2852	0.0159	4.41667E-06	0.0157	4.36111E-06	19.49685535	43.6132233	19.74522293	44.16880577
30	0.8405	0.8436	0.8566	0.8593	0.0161	4.47222E-06	0.0157	4.36111E-06	19.25465839	43.07144413	19.74522293	44.16880577
30	0.1824	0.1857	0.1986	0.2015	0.0162	0.0000045	0.0158	4.38889E-06	19.13580247	42.80557102	19.62025316	43.88925636
30	0.1569	0.1601	0.1728	0.1758	0.0159	4.41667E-06	0.0157	4.36111E-06	19.49685535	43.6132233	19.74522293	44.16880577
								Average	18.97388308	42.44336761	19.72382189	44.12093301
								Standard Dev	0.393827999	0.880968144	0.277988553	0.621838209
50	0.7775	0.7798	0.7891	0.7912	0.0116	3.22222E-06	0.0114	3.16667E-06	26.72413793	59.78019401	27.19298246	60.82896935
50	0.234	0.2361	0.2455	0.2469	0.0115	3.19444E-06	0.0108	0.000003	26.95652174	60.30002179	28.7037037	64.20835653
50	0.7587	0.7608	0.7695	0.7716	0.0108	3E-06	0.0108	3E-06	28.7037037	64.20835653	28.7037037	64.20835653
50	0.1118	0.1141	0.1234	0.1256	0.0116	3.22222E-06	0.0115	3.19444E-06	26.72413793	59.78019401	26.95652174	60.30002179
50	0.7419	0.7442	0.7531	0.7555	0.0112	3.11111E-06	0.0113	3.13889E-06	27.67857143	61.91520094	27.43362832	61.36727881
50	0.4211	0.4231	0.433	0.4343	0.0119	3.30556E-06	0.0112	3.11111E-06	26.05042017	58.2731303	27.67857143	61.91520094
50	0.6307	0.633	0.6418	0.644	0.0111	3.08333E-06	0.011	3.05556E-06	27.92792793	62.47299554	28.18181818	63.04093187
50	0.9006	0.9029	0.9121	0.9142	0.0115	3.19444E-06	0.0113	3.13889E-06	26.95652174	60.30002179	27.43362832	61.36727881
50	0.4423	0.4445	0.4535	0.4555	0.0112	3.11111E-06	0.011	3.05556E-06	27.67857143	61.91520094	28.18181818	63.04093187
50	0.1465	0.1488	0.1578	0.1601	0.0113	3.13889E-06	0.0113	3.13889E-05	27.43362832	61.36727881	27.43362832	61.36727881
50	0.1896	0.1917	0.2003	0.2024	0.0107	2.97222E-06	0.0107	2.97222E-06	28.97196262	64.80843483	28.97196262	64.80843483
50	0.6981	0.7002	0.7092	0.7109	0.0111	3.08333E-06	0.0107	2.97222E-06	27.92792793	62.47299554	28.97196262	64.80843483
50	0.0609	0.0632	0.0719	0.0741	0.011	3.05556E-06	0.0109	3.02778E-06	28.18181818	63.04093187	28.44036697	63.61928904
50	0.1744	0.1766	0.1858	0.1879	0.0114	3.16667E-06	0.0113	3.13889E-06	27.19298246	60.82896935	27.43362832	61.36727881
50	0.3739	0.3762	0.3851	0.3872	0.0112	3.11111E-06	0.011	3.05556E-06	27.67857143	61.91520094	28.18181818	63.04093187
50	0.5525	0.5548	0.5634	0.5657	0.0109	3.02778E-06	0.0109	3.02778E-06	28.44036697	63.61928904	28.44036697	63.61928904
50	0.2181	0.2203	0.2289	0.2311	0.0108	0.000003	0.0108	0.000003	28.7037037	64.20835653	28.7037037	64.20835653
50	0.3787	0.3809	0.3895	0.3918	0.0108	3E-06	0.0109	3.02778E-06	28.7037037	64.20835653	28.44036697	63.61928904
50	0.5814	0.5837	0.5925	0.5946	0.0111	3.08333E-06	0.0111	3.08333E-06	27.92792793	62.47299554	27.92792793	62.47299554
50	0.8654	0.8677	0.8767	0.879	0.0113	3.13889E-06	0.0113	3.13889E-06	27.43362832	61.36727881	27.43362832	61.36727881
								Average	27.69963678	61.96277017	28.04228585	62.72680916
								Standard Dev	0.784967304	1.75596659	0.6271371	1.402865736
70	0.7439	0.7457	0.7528	0.7547	0.0089	2.47222E-06	0.009	0.0000025	34.83146067	77.91575849	34.44444444	77.05002784
70	0.8352	0.8371	0.8445	0.8465	0.0093	2.58333E-06	0.0094	2.61111E-06	33.33333333	74.56454307	32.9787234	73.77130325
70	0.1279	0.1294	0.1368	0.1379	0.0089	2.47222E-06	0.0085	2.36111E-06	34.83146067	77.91575849	36.47058824	81.58238242
70	0.5901	0.5918	0.5992	0.6009	0.0091	2.52778E-06	0.0091	2.52778E-06	34.06593407	76.20332423	34.06593407	76.20332423
70	0.0013	0.0033	0.0108	0.0127	0.0095	2.63889E-06	0.0094	2.61111E-06	32.63157895	72.99476321	32.9787234	73.77130325
70	0.1927	0.1946	0.2015	0.205	0.0088	2.44444E-06	0.0104	2.88889E-06	35.22727273	78.80116483	29.80769231	66.67790871
70	0.4518	0.4537	0.4609	0.4628	0.0091	2.52778E-06	0.0091	2.52778E-06	34.06593407	76.20332423	34.06593407	76.20332423
70	0.7385	0.7403	0.7475	0.7492	0.009	0.0000025	0.0089	2.47222E-06	34.44444444	77.05002784	34.83146067	77.91575849
70	0.0985	0.1005	0.1077	0.1097	0.0092	2.55556E-06	0.0092	2.55556E-06	33.69565217	75.37502723	33.69565217	75.37502723
70	0.6755	0.6771	0.6853	0.6863	0.0098	2.72222E-06	0.0092	2.55556E-06	31.63265306	70.76022965	33.69565217	75.37502723
70	0.384	0.3857	0.3937	0.3949	0.0097	2.69444E-06	0.0092	2.55556E-06	31.95876289	71.48971655	33.69565217	75.37502723
70	0.8577	0.8592	0.8671	0.868	0.0094	2.61111E-06	0.0088	2.44444E-06	32.9787234	73.77130325	35.22727273	78.80116483
70	0.9091	0.9109	0.9179	0.9197	0.0088	2.44444E-06	0.0088	2.44444E-06	35.22727273	78.80116483	35.22727273	78.80116483
70	0.2995	0.3009	0.3088	0.3097	0.0093	2.58333E-06	0.0088	2.44444E-06	33.33333333	74.56454307	35.22727273	78.80116483
70	0.6196	0.6212	0.629	0.6303	0.0094	2.61111E-06	0.0091	2.52778E-06	32.9787234	73.77130325	34.06593407	76.20332423
70	0.216	0.2178	0.2245	0.2263	0.0085	2.36111E-06	0.0085	2.36111E-06	36.47058824	81.58238242	36.47058824	81.58238242
70	0.7526	0.7544	0.7615	0.7634	0.0089	2.47222E-06	0.009	0.0000025	34.83146067	77.91575849	34.44444444	77.05002784
70	0.5202	0.5217	0.53	0.5307	0.0098	2.72222E-06	0.009	2.5E-06	31.63265306	70.76022965	34.44444444	77.05002784
								Average	33.78729122	75.58001793	34.21320481	76.5327595
								Standard Dev	1.34814502	3.015714522	1.478160502	3.306550873
80	0.1397	0.1412	0.1476	0.149	0.0079	2.19444E-06	0.0078	2.16667E-06	39.24050633	87.77851273	39.74358974	88.90387827
80	0.7656	0.7673	0.7737	0.7754	0.0081	2.25E-06	0.0081	0.00000225	38.27160494	85.61114204	38.27160494	85.61114204
80	0.834	0.8356	0.8417	0.8433	0.0077	2.13889E-06	0.0077	2.13889E-06	40.25974026	90.0584741	40.25974026	90.0584741
80	0.1736	0.175	0.1818	0.183	0.0082	2.27778E-06	0.008	2.22222E-06	37.80487805	84.56710372	38.75	86.68128132
80	0.9332	0.9346	0.941	0.9423	0.0078	2.16667E-06	0.0077	2.13889E-06	39.74358974	88.90387827	40.25974026	90.0584741
80	0.6417	0.6433	0.6493	0.6509	0.0076	2.11111E-06	0.0076	2.11111E-06	40.78947368	91.24345402	40.78947368	91.24345402
80	0.4132	0.4148	0.4208	0.4224	0.0076	2.11111E-06	0.0076	2.11111E-06	40.78947368	91.24345402	40.78947368	91.24345402
80	0.0785	0.08	0.0861	0.0876	0.0076	2.11111E-06	0.0076	2.11111E-06	40.78947368	91.24345402	40.78947368	91.24345402
80	0.1689	0.1706	0.1769	0.1786	0.008	2.22222E-06	0.008	2.22222E-06	38.75	86.68128132	38.75	86.68128132
80	0.4501	0.4518	0.458	0.4597	0.0079	2.19444E-06	0.0079	2.19444E-06	39.24050633	87.77851273	39.24050633	87.77851273
80	0.3277	0.3323	0.3355	0.3407	0.0078	2.16667E-06	0.0084	2.33333E-06	39.74358974	88.90387827	36.9047619	82.55360125
80	0.0354	0.0368	0.0437	0.0448	0.0083	2.30556E-06	0.008	2.22222E-06	37.34939759	83.54822296	38.75	86.68128132
80	0.6009	0.6026	0.6091	0.6107	0.0082	2.27778E-06	0.0081	0.00000225	37.80487805	84.56710372	38.27160494	85.61114204
80	0.6968	0.6982	0.7046	0.7059	0.0078	2.16667E-06	0.0077	2.13889E-06	39.74358974	88.90387827	40.25974026	90.0584741
80	0.1596	0.161	0.1675	0.1688	0.0079	2.19444E-06	0.0078	2.16667E-06	39.24050633	87.77851273	39.74358974	88.90387827
80	0.8678	0.8693	0.8754	0.877	0.0076	2.11111E-06	0.0077	2.13889E-06	40.78947368	91.24345402	40.25974026	90.0584741
80	0.5803	0.5819	0.5882	0.5898	0.0079	2.19444E-06	0.0079	2.19444E-06	39.24050633	87.77851273	39.24050633	87.77851273
80	0.5488	0.5503	0.5565	0.558	0.0077	2.13889E-06	0.0077	2.13889E-06	40.25974026	90.0584741	40.25974026	90.0584741
								Average	39.43618269	88.21618354	39.5185159	88.40040243
								Standard Dev	1.101410971	2.463786175	1.072712281	2.390589032

Table 3 – Baseball

Juggs "Speed"	Break 1	Recovery 1	Break 2	Recovery 2	Break 1 - Break 2 (seconds)	(hours)	Recovery 1 - Recovery 2 (seconds)	(hours)	m/s - Break	mph - Break	m/s - Recovery	mph - Recovery
40	0.6649	0.6679	0.6782	0.6814	0.0133	3.6944E-06	0.0135	3.75E-06	23.30827068	52.13911658	22.96296296	51.36668522
40	0.0391	0.0418	0.0528	0.0557	0.0137	3.8056E-06	0.0139	3.86111E-06	22.62773723	50.61680661	22.30215827	49.88850723
40	0.2596	0.2627	0.273	0.2762	0.0134	3.7222E-06	0.0135	0.00000375	23.13432836	51.7500187	22.96296296	51.36668522
40	0.0895	0.0927	0.103	0.1062	0.0135	0.00000375	0.0135	0.00000375	22.96296296	51.36668522	22.96296296	51.36668522
40	0.8865	0.8896	0.9	0.9032	0.0135	3.75E-06	0.0136	3.77778E-06	22.96296296	51.36668522	22.79411765	50.98898901
40	0.8414	0.8445	0.8548	0.858	0.0134	3.7222E-06	0.0135	3.75E-06	23.13432836	51.7500187	22.96296296	51.36668522
40	0.1382	0.1413	0.1517	0.1549	0.0135	0.00000375	0.0136	3.77778E-06	22.96296296	51.36668522	22.79411765	50.98898901
40	0.253	0.2561	0.2665	0.2696	0.0135	0.00000375	0.0135	0.00000375	22.96296296	51.36668522	22.96296296	51.36668522
40	0.7655	0.7686	0.779	0.7822	0.0135	3.75E-06	0.0136	3.77778E-06	22.96296296	51.36668522	22.79411765	50.98898901
40	0.4087	0.4119	0.4223	0.4255	0.0136	3.7778E-06	0.0136	3.77778E-06	22.79411765	50.98898901	22.79411765	50.98898901
40	0.5576	0.5605	0.5709	0.5739	0.0133	3.6944E-06	0.0134	3.72222E-06	23.30827068	52.13911658	23.13432836	51.7500187
40	0.8791	0.8822	0.8925	0.8957	0.0134	3.7222E-06	0.0135	3.75E-06	23.13432836	51.7500187	22.96296296	51.36668522
40	0.8701	0.8732	0.8835	0.8867	0.0134	3.7222E-06	0.0135	3.75E-06	23.13432836	51.7500187	22.96296296	51.36668522
40	0.7614	0.7645	0.7748	0.778	0.0134	3.7222E-06	0.0135	3.75E-06	23.13432836	51.7500187	22.96296296	51.36668522
40	0.5408	0.5441	0.5541	0.5574	0.0133	3.6944E-06	0.0133	3.69444E-06	23.30827068	52.13911658	23.30827068	52.13911658
40	0.8477	0.8508	0.861	0.8642	0.0133	3.6944E-06	0.0134	3.72222E-06	23.30827068	52.13911658	23.13432836	51.7500187
40	0.554	0.5572	0.5674	0.5705	0.0134	3.7222E-06	0.0133	3.69444E-06	23.13432836	51.7500187	23.30827068	52.13911658
40	0.7094	0.7125	0.7228	0.7259	0.0134	3.7222E-06	0.0134	3.72222E-06	23.13432836	51.7500187	23.13432836	51.7500187
40	0.9692	0.9724	0.9825	0.9858	0.0133	3.6944E-06	0.0134	3.72222E-06	23.30827068	52.13911658	23.13432836	51.7500187
40	0.9691	0.9722	0.9823	0.9856	0.0132	3.6667E-06	0.0134	3.72222E-06	23.48484848	52.53410989	23.13432836	51.7500187
								Average	23.1101585	51.69585227	22.97352579	51.39031359
								Standard Dev	0.202831116	0.453720284	0.221688694	0.495903485
60	0.1513	0.1537	0.1625	0.1649	0.0112	3.1111E-06	0.0112	3.11111E-06	27.67857143	61.91520094	27.67857143	61.91520094
60	0.669	0.6712	0.6804	0.6822	0.0114	3.1667E-06	0.011	3.05556E-06	27.19298246	60.82896935	28.18181818	63.04093187
60	0.6946	0.6969	0.7061	0.7084	0.0115	3.1944E-06	0.0115	3.19444E-06	26.95652174	60.30002179	26.95652174	60.30002179
60	0.3483	0.3506	0.3597	0.3619	0.0114	3.1667E-06	0.0113	3.13889E-06	27.19298246	60.82896935	27.43362832	61.36727881
60	0.2771	0.2792	0.2885	0.2904	0.0114	3.1667E-06	0.0112	3.11111E-06	27.19298246	60.82896935	27.67857143	61.91520094
60	0.8184	0.8208	0.83	0.8319	0.0116	3.2222E-06	0.0111	3.08333E-06	26.72413793	59.78019401	27.92792793	62.47299554
60	0.724	0.7266	0.7352	0.7379	0.0112	3.1111E-06	0.0113	3.13889E-06	27.67857143	61.91520094	27.43362832	61.36727881
60	0.3805	0.3831	0.3918	0.3944	0.0113	3.1389E-06	0.0113	3.13889E-06	27.43362832	61.36727881	27.43362832	61.36727881
60	0.08	0.0826	0.0913	0.0939	0.0113	3.1389E-06	0.0113	3.13889E-06	27.43362832	61.36727881	27.43362832	61.36727881
60	0.024	0.0266	0.0353	0.0379	0.0113	3.1389E-06	0.0113	3.13889E-06	27.43362832	61.36727881	27.43362832	61.36727881
60	0.5497	0.5521	0.5611	0.5631	0.0114	3.1667E-06	0.011	3.05556E-06	27.19298246	60.82896935	28.18181818	63.04093187
60	0.7876	0.7902	0.7989	0.8015	0.0113	3.1389E-06	0.0113	3.13889E-06	27.43362832	61.36727881	27.43362832	61.36727881
60	0.9018	0.9044	0.9131	0.9156	0.0113	3.1389E-06	0.0112	3.11111E-06	27.43362832	61.36727881	27.67857143	61.91520094
60	0.4114	0.4141	0.4228	0.4255	0.0114	3.1667E-06	0.0114	3.16667E-06	27.19298246	60.82896935	27.19298246	60.82896935
60	0.8113	0.8138	0.8226	0.8251	0.0113	3.1389E-06	0.0113	3.13889E-06	27.43362832	61.36727881	27.43362832	61.36727881
60	0.0402	0.0427	0.0516	0.0538	0.0114	3.1667E-06	0.0111	3.08333E-06	27.19298246	60.82896935	27.92792793	62.47299554
60	0.2298	0.2322	0.2408	0.2435	0.0112	3.1111E-06	0.0113	3.13889E-06	27.67857143	61.91520094	27.43362832	61.36727881
60	0.6793	0.6818	0.6906	0.6932	0.0113	3.1389E-06	0.0114	3.16667E-06	27.43362832	61.36727881	27.19298246	60.82896935
60	0.9456	0.9482	0.9569	0.9594	0.0113	3.1389E-06	0.0112	3.11111E-06	27.43362832	61.36727881	27.67857143	61.91520094
60	0.9558	0.9611	0.9701	0.9722	0.0113	3.1389E-06	0.0111	3.08333E-06	27.43362832	61.36727881	27.92792793	62.47299554
								Average	27.33884618	61.1552572	27.58366095	61.70289225
								Standard Dev	0.238282029	0.533021719	0.323290377	0.723179976

Table 4 – Softball

Juggs "Speed"	Break 1	Recovery 1	Break 2	Recovery 2	Break 1 - Break 2 (seconds)	(hours)	Recovery 1 - Recovery 2 (seconds)	(hours)	m/s - Break	mph - Break	m/s - Recovery	mph - Recovery
60	0.0879	0.091	0.0986	0.1018	0.0107	2.97222E-06	0.0108	0.000003	28.97196262	64.80843463	28.7037037	64.20835653
60	0.8364	0.84	0.848	0.8516	0.0116	3.22222E-06	0.0116	3.22222E-06	26.72413793	59.78019401	26.72413793	59.78019401
60	0.3757	0.3791	0.387	0.3903	0.0113	3.13889E-06	0.0112	3.11111E-06	27.43362832	61.36727881	27.67857143	61.91520094
60	0.3175	0.3209	0.3288	0.3324	0.0113	3.13889E-06	0.0115	3.19444E-06	27.43362832	61.36727881	26.95652174	60.30002179
60	0.6651	0.6683	0.6756	0.6788	0.0105	2.91667E-06	0.0105	2.91667E-06	29.52380952	66.042881	29.52380952	66.042881
60	0.4362	0.4395	0.4469	0.45	0.0107	2.97222E-06	0.0105	2.91667E-06	28.97196262	64.80843463	29.52380952	66.042881
60	0.6359	0.6396	0.6477	0.6511	0.0118	3.27778E-06	0.0115	3.19444E-06	26.27118644	58.76697038	26.95652174	60.30002179
60	0.4192	0.4225	0.43	0.4333	0.0108	3E-06	0.0108	3E-06	28.7037037	64.20835653	28.7037037	64.20835653
60	0.4774	0.4807	0.4882	0.4916	0.0108	3E-06	0.0109	3.02778E-06	28.7037037	64.20835653	28.44036697	63.61928904
60	0.952	0.9553	0.9629	0.9664	0.0109	3.02778E-06	0.0111	3.08333E-06	28.44036697	63.61928904	27.92792793	62.47299554
60	0.9596	0.9628	0.97	0.9732	0.0104	2.88889E-06	0.0104	2.88889E-06	29.80769231	66.67790871	29.80769231	66.67790871
60	0.654	0.6573	0.6645	0.6678	0.0105	2.91667E-06	0.0105	2.91667E-06	29.52380952	66.042881	29.52380952	66.042881
60	0.0203	0.0236	0.0311	0.0344	0.0108	0.000003	0.0108	0.000003	28.7037037	64.20835653	28.7037037	64.20835653
60	0.2473	0.2503	0.257	0.2601	0.0097	2.69444E-06	0.0098	2.72222E-06	31.95876289	71.48971655	31.63265306	70.76022965
60	0.3457	0.3489	0.3561	0.3592	0.0104	2.88889E-06	0.0103	2.86111E-06	29.80769231	66.67790871	30.09708738	67.32526704
60	0.509	0.5122	0.5191	0.5222	0.0101	2.80556E-06	0.01	2.77778E-06	30.69306931	68.65844065	31	69.34502505
60	0.957	0.9602	0.9679	0.9712	0.0109	3.02778E-06	0.011	3.05556E-06	28.44036697	63.61928904	28.18181818	63.04093187
60	0.5883	0.5914	0.5985	0.6016	0.0102	2.83333E-06	0.0102	2.83333E-06	30.39215686	67.98531868	30.39215686	67.98531868
60	0.3291	0.3322	0.3392	0.3423	0.0101	2.80556E-06	0.0101	2.80556E-06	30.69306931	68.65844065	30.69306931	68.65844065
60	0.9424	0.9456	0.9527	0.9558	0.0103	2.86111E-06	0.0102	2.83333E-06	30.09708738	67.32526704	30.39215686	67.98531868
								Average	29.06477504	65.0160501	29.07816107	66.0459938
								Standard Dev	1.410913368	3.156123317	1.412409533	3.159470145
70	0.4451	0.4481	0.4548	0.4578	0.0097	2.69444E-06	0.0097	2.69444E-06	31.95876289	71.48971655	31.95876289	71.48971655
70	0.523	0.5259	0.5323	0.5353	0.0093	2.58333E-06	0.0094	2.61111E-06	33.33333333	74.56454307	32.9787234	73.77130325
70	0.3048	0.308	0.3153	0.3185	0.0105	2.91667E-06	0.0105	2.91667E-06	29.52380952	66.042881	29.52380952	66.042881
70	0.0489	0.0518	0.0585	0.0614	0.0096	2.66667E-06	0.0096	2.66667E-06	32.29166667	72.2344011	32.29166667	72.2344011
70	0.9456	0.9486	0.9552	0.9581	0.0096	2.66667E-06	0.0095	2.63889E-06	32.29166667	72.2344011	32.63157895	72.99476321
70	0.8131	0.816	0.8226	0.8256	0.0095	2.63889E-06	0.0096	2.66667E-06	32.63157895	72.99476321	32.29166667	72.2344011
70	0.4332	0.4361	0.4427	0.4457	0.0095	2.63889E-06	0.0096	2.66667E-06	32.63157895	72.99476321	32.29166667	72.2344011
70	0.2416	0.2445	0.2513	0.2544	0.0097	2.69444E-06	0.0099	2.75E-06	31.95876289	71.48971655	31.31313131	70.04547985
70	0.9604	0.9635	0.9701	0.9731	0.0097	2.69444E-06	0.0096	2.66667E-06	31.95876289	71.48971655	32.29166667	72.2344011
70	0.3269	0.3298	0.3364	0.3394	0.0095	2.63889E-06	0.0096	2.66667E-06	32.63157895	72.99476321	32.29166667	72.2344011
70	0.8051	0.8081	0.8149	0.8179	0.0098	2.72222E-06	0.0098	2.72222E-06	31.63265306	70.76022965	31.63265306	70.76022965
70	0.8892	0.8922	0.8987	0.9016	0.0095	2.63889E-06	0.0094	2.61111E-06	32.63157895	72.99476321	32.9787234	73.77130325
70	0.2874	0.2902	0.2966	0.2994	0.0092	2.55556E-06	0.0092	2.55556E-06	33.69565217	75.37502723	33.69565217	75.37502723
70	0.0434	0.0465	0.0535	0.0567	0.0101	2.80556E-06	0.0102	2.83333E-06	30.69306931	68.65844065	30.39215686	67.98531868
70	0.0582	0.0615	0.0687	0.072	0.0105	2.91667E-06	0.0105	2.91667E-06	29.52380952	66.042881	29.52380952	66.042881
70	0.0375	0.0405	0.0473	0.0504	0.0098	2.72222E-06	0.0099	0.00000275	31.63265306	70.76022965	31.31313131	70.04547985
70	0.7749	0.7779	0.785	0.7881	0.0101	2.80556E-06	0.0102	2.83333E-06	30.69306931	68.65844065	30.39215686	67.98531868
70	0.2003	0.2032	0.2095	0.2124	0.0092	2.55556E-06	0.0092	2.55556E-06	33.69565217	75.37502723	33.69565217	75.37502723
70	0.2661	0.2689	0.2753	0.2781	0.0092	2.55556E-06	0.0092	2.55556E-06	33.69565217	75.37502723	33.69565217	75.37502723
70	0.6878	0.6907	0.6972	0.7001	0.0094	2.61111E-06	0.0094	2.61111E-06	32.9787234	73.77130325	32.9787234	73.77130325
								Average	32.10420074	71.81505177	32.00813252	71.60015327
								Standard Dev	1.232543376	2.757121009	1.273947511	2.849739421
80	0.5963	0.5989	0.6052	0.6078	0.0089	2.47222E-06	0.0089	2.47222E-06	34.83146067	77.91575849	34.83146067	77.91575849
80	0.4051	0.408	0.4146	0.4175	0.0095	2.63889E-06	0.0095	2.63889E-06	32.63157895	72.99476321	32.63157895	72.99476321
80	0.9682	0.9711	0.9775	0.9801	0.0093	2.58333E-06	0.009	0.0000025	33.33333333	74.56454307	34.44444444	77.05002784
80	0.7756	0.7783	0.7844	0.7872	0.0088	2.44444E-06	0.0089	2.47222E-06	35.22727273	78.80116483	34.83146067	77.91575849
80	0.6215	0.6242	0.6308	0.6335	0.0093	2.58333E-06	0.0093	2.58333E-06	33.33333333	74.56454307	33.33333333	74.56454307
80	0.1261	0.1289	0.1353	0.1381	0.0092	2.55556E-06	0.0092	2.55556E-06	33.69565217	75.37502723	33.69565217	75.37502723
80	0.8688	0.8715	0.8777	0.8806	0.0089	2.47222E-06	0.0091	2.52778E-06	34.83146067	77.91575849	34.06593407	76.20332423
80	0.7803	0.7832	0.7898	0.7922	0.0093	2.58333E-06	0.009	0.0000025	33.33333333	74.56454307	34.44444444	77.05002784
80	0.484	0.4867	0.4935	0.4961	0.0095	2.63889E-06	0.0094	2.61111E-06	32.63157895	72.99476321	32.9787234	73.77130325
80	0.5694	0.5721	0.5783	0.5811	0.0089	2.47222E-06	0.009	2.5E-06	34.83146067	77.91575849	34.44444444	77.05002784
80	0.2397	0.2425	0.2487	0.2515	0.009	0.0000025	0.009	0.0000025	34.44444444	77.05002784	34.44444444	77.05002784
80	0.6036	0.6063	0.613	0.6158	0.0094	2.61111E-06	0.0095	2.63889E-06	32.9787234	73.77130325	32.63157895	72.99476321
80	0.2899	0.2928	0.2993	0.302	0.0094	2.61111E-06	0.0092	2.55556E-06	32.9787234	73.77130325	33.69565217	75.37502723
80	0.5473	0.55	0.5565	0.5592	0.0092	2.55556E-06	0.0092	2.55556E-06	33.69565217	75.37502723	33.69565217	75.37502723
80	0.5632	0.5655	0.5725	0.5746	0.0093	2.58333E-06	0.0091	2.52778E-06	33.33333333	74.56454307	34.06593407	76.20332423
80	0.9672	0.9699	0.9761	0.9789	0.0089	2.47222E-06	0.009	0.0000025	34.83146067	77.91575849	34.44444444	77.05002784
80	0.3254	0.3281	0.3344	0.337	0.009	2.5E-06	0.0089	2.47222E-06	34.44444444	77.05002784	34.83146067	77.91575849
80	0.0929	0.0952	0.102	0.104	0.0091	2.52778E-06	0.0088	2.44444E-06	34.06593407	76.20332423	35.22727273	78.80116483
80	0.103	0.1054	0.1117	0.1142	0.0087	2.41667E-06	0.0088	2.44444E-06	35.63218391	79.70692535	35.22727273	78.80116483
80	0.8228	0.8254	0.8315	0.8342	0.0087	2.41667E-06	0.0088	2.44444E-06	35.63218391	79.70692535	35.22727273	78.80116483
								Average	33.74075611	75.47582185	33.88231589	75.79258206
								Standard Dev	0.888852319	1.943119897	0.731164372	1.635545749

Table 5 – Volleyball

Juggs "Speed"	Break 1	Recovery 1	Break 2	Recovery 2	Break 1 - Break 2 (seconds)	(hours)	Recovery 1 - Recovery 2 (seconds)	(hours)	m/s - Break	mph - Break	m/s - Recovery	mph - Recovery
40	0.2437	0.2628	0.2722	0.2915	0.0285	8E-06	0.0287	7.97222E-06	10.877193	24.33158774	10.80139373	24.16202984
40	0.7805	0.7996	0.8066	0.8254	0.0261	7E-06	0.0258	7.16667E-06	11.8773946	26.56897512	12.01550388	26.87791669
40	0.4544	0.4723	0.4808	0.4985	0.0264	7E-06	0.0262	7.27778E-06	11.7424242	26.26705494	11.83206107	26.46756681
40	0.1707	0.1879	0.1962	0.2133	0.0255	7E-06	0.0254	7.05556E-06	12.1568627	27.19412747	12.20472441	27.30119097
40	0.5502	0.568	0.5763	0.5939	0.0261	7E-06	0.0259	7.19444E-06	11.8773946	26.56897512	11.96911197	26.77414095
40	0.0194	0.0373	0.0459	0.0635	0.0265	7E-06	0.0262	7.27778E-06	11.6981132	26.16793398	11.83206107	26.46756681
40	0.3645	0.3815	0.3894	0.4064	0.0249	7E-06	0.0249	6.91667E-06	12.4497992	27.84940765	12.4497992	27.84940765
40	0.3659	0.3828	0.3907	0.4075	0.0248	7E-06	0.0247	6.86111E-06	12.5	27.96170365	12.55060729	28.07490893
40	0.6471	0.6639	0.6718	0.6885	0.0247	7E-06	0.0246	6.83333E-06	12.5506073	28.07490893	12.60162602	28.18903457
40	0.7548	0.7721	0.7802	0.7974	0.0254	7E-06	0.0253	7.02778E-06	12.2047244	27.30118097	12.25296443	27.40910081
40	0.7261	0.7429	0.7511	0.7681	0.025	7E-06	0.0252	0.000007	12.4	27.73801002	12.3015873	27.51786708
40	0.0301	0.0464	0.0644	0.0708	0.0343	1E-05	0.0244	6.77778E-06	9.03790087	20.21720847	12.70491803	28.42009224
40	0.0147	0.0312	0.0392	0.0558	0.0245	7E-06	0.0246	6.83333E-06	12.6530612	28.30409186	12.60162602	28.18903457
40	0.3452	0.3621	0.3702	0.387	0.025	7E-06	0.0249	6.91667E-06	12.4	27.73801002	12.4497992	27.84940765
40	0.5361	0.5516	0.5591	0.5747	0.023	6E-06	0.0231	6.41667E-06	13.4782609	30.15001089	13.41991342	30.01949137
40	0.3861	0.4029	0.411	0.4277	0.0249	7E-06	0.0248	6.88889E-06	12.4497992	27.84940765	12.5	27.96170365
40	0.0473	0.0641	0.0721	0.089	0.0248	7E-06	0.0249	6.91667E-06	12.5	27.96170365	12.4497992	27.84940765
40	0.1789	0.1951	0.2028	0.2189	0.0239	7E-06	0.0238	6.61111E-06	12.9707113	29.01465483	13.02521008	29.13658515
40	0.9303	0.9465	0.9541	0.9703	0.0238	7E-06	0.0238	6.61111E-06	13.0252101	29.13658515	13.02521008	29.13658515
40	0.7164	0.733	0.741	0.7573	0.0246	7E-06	0.0243	0.00000675	12.601626	28.18903457	12.75720165	28.53704735
								Average	12.1725541	27.22922813	12.3872559	27.70950228
								Standard Dev	0.92304224	2.064786676	0.550805014	1.232115726
60	0.6214	0.635	0.6413	0.6548	0.0199	6E-06	0.0198	5.5E-06	15.5778894	34.84874626	15.65656566	35.02273993
60	0.011	0.0248	0.0312	0.045	0.0202	6E-06	0.0204	5.66667E-06	15.3465347	34.32922032	15.19607843	33.99265934
60	0.4366	0.4503	0.4568	0.4704	0.02	6E-06	0.0201	5.58333E-06	15.5	34.67251253	15.42288557	34.50001246
60	0.7318	0.7449	0.7512	0.7644	0.0194	5E-06	0.0195	5.41667E-06	15.9793814	35.74485828	15.8974359	35.56155131
60	0.2301	0.2432	0.2496	0.2628	0.0195	5E-06	0.0196	5.44444E-06	15.8974359	35.56155131	15.81632653	35.38011482
60	0.6752	0.6885	0.6949	0.7082	0.0197	5E-06	0.0197	5.47222E-06	15.7360406	35.20052033	15.73604061	35.20052033
60	0.1896	0.2028	0.2091	0.2225	0.0195	5E-06	0.0197	5.47222E-06	15.8974359	35.56155131	15.73604061	35.20052033
60	0.1639	0.1776	0.1845	0.1982	0.0206	6E-06	0.0206	5.72222E-06	15.0485437	33.66263352	15.04854369	33.66263352
60	0.3732	0.3868	0.3932	0.4069	0.02	6E-06	0.0201	5.58333E-06	15.5	34.67251253	15.42288557	34.50001246
60	0.0804	0.094	0.1006	0.1143	0.0202	6E-06	0.0203	5.63889E-06	15.3465347	34.32922032	15.27093596	34.16011086
60	0.5748	0.5886	0.5955	0.6093	0.0207	6E-06	0.0207	5.75E-06	14.9758454	33.5000121	14.97584541	33.5000121
60	0.8091	0.8224	0.8288	0.8423	0.0197	5E-06	0.0199	5.52778E-06	15.7360406	35.20052033	15.57788945	34.84874626
60	0.1021	0.1152	0.1216	0.1347	0.0195	5E-06	0.0195	5.41667E-06	15.8974359	35.56155131	15.8974359	35.56155131
60	0.4422	0.4558	0.4624	0.4761	0.0202	6E-06	0.0203	5.63889E-06	15.3465347	34.32922032	15.27093596	34.16011086
60	0.5914	0.6042	0.6103	0.6232	0.0189	5E-06	0.019	5.27778E-06	16.4021164	36.69048945	16.31578947	36.49738161
60	0.3477	0.3609	0.3673	0.3806	0.0196	5E-06	0.0197	5.47222E-06	15.8163265	35.38011482	15.73604061	35.20052033
60	0.2848	0.2976	0.3038	0.3166	0.019	5E-06	0.019	5.27778E-06	16.3157895	36.49738161	16.31578947	36.49738161
60	0.1941	0.2075	0.2138	0.2273	0.0197	5E-06	0.0198	0.0000055	15.7360406	35.20052033	15.65656566	35.02273993
60	0.4529	0.466	0.4723	0.4855	0.0194	5E-06	0.0195	5.41667E-06	15.9793814	35.74485828	15.8974359	35.56155131
60	0.0296	0.0428	0.0491	0.0624	0.0195	5E-06	0.0196	5.44444E-06	15.8974359	35.56155131	15.81632653	35.38011482
								Average	15.6966372	35.11237733	15.63318964	34.97044928
								Standard Dev	0.37133598	0.830654921	0.387080739	0.821136228
80	0.2933	0.3052	0.311	0.3229	0.0177	5E-06	0.0177	4.91667E-06	17.5141243	39.17798026	17.51412429	39.17798026
80	0.3492	0.3609	0.3665	0.3782	0.0173	5E-06	0.0173	4.80556E-06	17.9190751	40.08382951	17.91907514	40.08382951
80	0.5723	0.5847	0.5908	0.6033	0.0185	5E-06	0.0186	5.16667E-06	16.7567568	37.48379739	16.66666667	37.28227153
80	0.6715	0.683	0.6888	0.7004	0.0173	5E-06	0.0174	4.83333E-06	17.9190751	40.08382951	17.81609195	39.85346267
80	0.3368	0.3483	0.3538	0.3654	0.017	5E-06	0.0171	0.00000475	18.2352941	40.79119121	18.12865497	40.55264623
80	0.4683	0.48	0.4856	0.4973	0.0173	5E-06	0.0173	4.80556E-06	17.9190751	40.08382951	17.91907514	40.08382951
80	0.0908	0.1026	0.108	0.1201	0.0172	5E-06	0.0175	4.86111E-06	18.0232558	40.31687503	17.71428571	39.6257286
80	0.3597	0.3712	0.377	0.3887	0.0173	5E-06	0.0175	4.86111E-06	17.9190751	40.08382951	17.71428571	39.6257286
80	0.5825	0.5949	0.6007	0.6132	0.0182	5E-06	0.0183	5.08333E-06	17.032967	38.10166212	16.93989071	37.89345831
80	0.2221	0.233	0.2391	0.25	0.017	5E-06	0.017	4.72222E-06	18.2352941	40.79119121	18.23529412	40.79119121
80	0.3452	0.3559	0.3623	0.3731	0.0171	5E-06	0.0172	4.77778E-06	18.128655	40.55264623	18.02325581	40.31687503
80	0.7665	0.7782	0.7845	0.7961	0.018	5E-06	0.0179	4.97222E-06	17.2222222	38.52501392	17.31843575	38.74023746
80	0.8991	0.9112	0.9172	0.9289	0.0181	5E-06	0.0177	4.91667E-06	17.1270718	38.31216854	17.51412429	39.17798026
80	0.8054	0.8173	0.8227	0.8346	0.0173	5E-06	0.0173	4.80556E-06	17.9190751	40.08382951	17.91907514	40.08382951
80	0.9067	0.9189	0.9245	0.9367	0.0178	5E-06	0.0178	4.94444E-06	17.4157303	38.95787924	17.41573034	38.95787924
80	0.4545	0.4655	0.4723	0.4826	0.0178	5E-06	0.0171	4.75E-06	17.4157303	38.95787924	18.12865497	40.55264623
80	0.4673	0.4782	0.4856	0.4964	0.0183	5E-06	0.0182	5.05556E-06	16.9398907	37.89345631	17.03296703	38.10166212
80	0.5773	0.589	0.5949	0.6063	0.0176	5E-06	0.0173	4.80556E-06	17.8136364	39.40058242	17.91907514	40.08382951
80	0.3245	0.3353	0.3426	0.3534	0.0181	5E-06	0.0181	5.02778E-06	17.1270718	38.31216854	17.12707182	38.31216854
80	0.1123	0.1242	0.1301	0.1421	0.0178	5E-06	0.0179	4.97222E-06	17.4157303	38.95787924	17.31843575	38.74023746
								Average	17.5899403	39.34757592	17.61421353	39.40187349
								Standard Dev	0.45541367	1.018731819	0.439917098	0.984066522

Summary of Results

Tennis Ball

With a Jugg speed of 20:

Avg ball speed was 30.15 mph with a standard deviation of 0.2252

With a Jugg speed of 30:

Avg ball speed was 43.28 mph with a standard deviation of 0.7514

With a Jugg speed of 50:

Avg ball speed was 62.345 mph with a standard deviation of 0.1.579

With a Jugg speed of 70:

Avg ball speed was 76.06 mph with a standard deviation of 3.161

With a Jugg speed of 80:

Avg ball speed was 88.31 mph with a standard deviation of 2.430

Baseball

With a Jugg speed of 40:

Avg ball speed was 51.54 mph with a standard deviation of 0.4748

With a Jugg speed of 60:

Avg ball speed was 61.43 mph with a standard deviation of 0.6280

Softball

With a Jugg speed of 60:

Avg ball speed was 65.025 mph with a standard deviation of 3.157

With a Jugg speed of 70:

Avg ball speed was 71.71 mph with a standard deviation of 2.803

With a Jugg speed of 80:

Avg ball speed was 75.633 mph with a standard deviation of 1.789

Volleyball

With a Jugg speed of 40:

Avg ball speed was 27.46 mph with a standard deviation of 1.648

With a Jugg speed of 60:

Avg ball speed was 35.04 mph with a standard deviation of 0.8259

With a Jugg speed of 80:

Avg ball speed was 39.37 mph with a standard deviation of 1.001

Conclusions

The Nike ballistics testing instrument is an excellent way to test the impact resistance of different eyewear at different controlled velocities using different balls from different sports. Due to the modifications of the Juggs machine, the speeds recorded on the dial were no longer accurate. Also, different balls have different variables including size, diameter, mass, and material, meaning that when the instrument is calibrated for one sport, the speeds will not carry over to another sport. The research completed here provided actual speeds of balls traveling at speeds recorded on the dial of a Juggs machine. For smaller balls, the Juggs machine tended to slightly underestimate the true speed; however, the opposite was true for the larger ball tested in this project. The results showed consistency, with the greatest standard deviation coming for a tennis ball with a Juggs recorded speed of 70 (actual value 76.06 ± 3.161 mph).

Throughout the testing, a few ideas arose that call for further testing. The first involves the variability of revolutions per minute (RPM) of the Juggs' wheels. If there is a great difference between trials, this could make the standard deviation greater. Also, if there is a difference between testing on different days, then the results of our calibration findings here would not be valid. We propose that this issue be investigated in the on-going phases of this study in order to improve the validity of our research.

A second issue that arose during testing was the variability of conditions of the ball we were testing. On the first trial, the ball used was in superb condition. However, after 20 trials, the ball was beginning to get scuffed up and lose its consistency. It would be interesting to note whether or not using an old ball instead of a fresh ball does in fact contribute to any significant differences in the speeds measured during this experiment.

The third and final issue that needs to be investigated is whether or not there is a difference in the measured speed depending on how the ball is placed in the ramp. Sometimes, as was the case with the larger volleyball, the ball needed a gentle nudge to begin its descent down the ramp. We cannot say with certainty whether or not it was nudged with the same amount of force between trials, and therefore cannot say with certainty whether or not our variability between measured speeds is truly representative of the Nike ballistics machine or our methods. This needs to be explored not only for the larger volleyball, but also for the other balls that intend to be tested using this instrument in case of tester variability.

Follow-up regarding the high-speed camera system should also be completed at a later date when the instrument is ready for trials. To be able to see the way the eyewear reacts at impact would be beneficial not only for frame design, but also to see how much inconsistency there is between the location at which the ball strikes the eyewear. The calculations for the specifications needed for this camera are included in the methods section of this write-up, as well as two companies who were willing to assist in any way they could.

As far as making the device more aesthetically pleasing, this may be difficult without radical reconstruction. At certain RPMs, the Juggs machine causes the entire base of the ballistics machine to vibrate. These vibrations cause the laser, the mirrors, and the sensor to all vibrate, too. The problem with this is that they do not vibrate in unison, which causes the beam to not strike the sensor and therefore lead to an incomplete laser gate. A couple of ways that this could possibly be remedied include the separation of the Juggs machine from the enclosed impact zone or to set up two laser-sensor switches. However, each of these comes with added disadvantages as well. By separating the Juggs machine from the rest of the ballistics testing device, we are increasing the need for perfect alignment of the entire device. If the angle at which the ball is expelled is off by a minimal amount, it runs the risk of striking the head-form at an oblique angle and giving invalid results. Also, it increases the risk of the ball missing the pre-constructed opening through which it needs to travel to strike the head-form, thereby increasing the chances of operator injury. By mounting two laser-sensor switches, we would eliminate the need for precision in the alignment of the mirrors. However, we would still have to have the lasers striking the sensor without any interruption, and with the shaking of the ballistics device, this may pose quite the challenge.